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DOI: will be set by the publisher

Spinorial Regge trajectories and Hagedorn-like temperatures

Spinorial space-time and preons as an alternative to strings

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Abstract. The development of the statistical bootstrap model for hadrons, quarks and nuclear matter occurred during the 1960s and the 1970s in a period of exceptional theoretical creativity. And if the transition from hadrons to quarks and gluons as fundamental particles was then operated, a transition from standard particles to preons and from the standard space-time to a spinorial one may now be necessary, including related pre-Big Bang scenarios. We present here a brief historical analysis of the scientific problematic of the 1960s in Particle Physics and of its evolution until the end of the 1970s, including cosmological issues. Particular attention is devoted to the exceptional role of Rolf Hagedorn and to the progress of the statisticak boostrap model until the experimental search for the quark-gluon plasma started being considered. In parallel, we simultaneously expose recent results and ideas concerning Particle Physics and in Cosmology, an discuss current open questions. Assuming preons to be constituents of the physical vacuum and the standard particles excitations of this vacuum (the superbradyon hypothesis we introduced in 1995), together with a spinorial space-time (SST), a new kind of Regge trajectories is expected to arise where the angular momentum spacing will be of 1/2 instead of 1. Standard particles can lie on such Regge trajectories inside associated internal symmetry multiplets, and the preonic vacuum structure can generate a new approach to Quantum Field Theory. As superbradyons are superluminal preons, some of the vacuum excitations can have critical speeds larger than the speed of light c, but the cosmological evolution selects by itself the particles with the smallest critical speed (the speed of light). In the new Particle Physics and Cosmology emerging from the pattern thus developed, Hagedorn-like temperatures will naturally be present. As new space, time, momentum and energy scales are expected to be generated by the preonic vacuum dynamics, the Planck scale does not necessarily make sense in the new scenario. It also turns out that two potential evidences for a superbradyonic vacuum with a SST geometry exist already: i) the recent results on quantum entanglement at large distances favoring superluminal propagation of signals and correlations ; ii) the anisotropy of the cosmic microwave background radiation between two hemispheres observed by the Planck Collaboration, in agreement with the predictions of cosmic SST automatically generating a privileged space direction for each comoving observer. Simultaneously to the discussion of the large number of open questions, we comment on the required experimental and observational programs.

This paper is dedicated to the memory of Rolf Hagedorn

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1 Introduction

January 1965, 50 years ago, is the date of the historical CERN preprint by Rolf Hagedorn on the statistical thermodynamics of strong interactions at high energies [1]. It was a long and detailed paper, published the same year in the *Supplemento al Nuovo Cimento* [2]. In this early work, a value of 158 MeV for the hadronic highest temperature was already used to fit data. In a CERN preprint of October 1964 [3, 4], Hagedorn had used the title *Thermodynamics of Distinguishable Particles: A Key to High-Energy Strong Interactions?* and referred to a hadron highest temperature close to the pion mass. The abstract of [1] starts saying:

In this statistical-thermodynamical approach to strong interactions at high energies it is assumed that higher and higher resonances of strongly interacting particles occur and take part in the thermodynamics as if they were particles.

(end of quote)

It was simultaneously more and more clear that hadrons are not elementary particles. In 1963-64, the quark model had also been formulated [5, 6] by Murray Gell-Mann [7], George Zweig [8, 9] and André Petermann [10]. Although the questions raised with such a hypothesis were more fundamental, this new approach to the internal structure of hadrons did not invalidate the grounds of the Hagedorn thermodynamics even if an upgrade was necessary in the 1970s.

Later (1966 and 1967), together with Johannes Ranft, Hagedorn produced two other preprints entitled similarly [11, 12] and published in 1968 in the *Supplemento al Nuovo Cimento* [13, 14]. The three papers on the statistical thermodynamics of strong interactions at high energies, together with a september 1967 preprint by Hagedorn entitled *On the hadronic mass spectrum* [15, 16] were resumed by Rolf Hagedorn in a November 1967 CERN preprint [17] that was published in *Il Nuovo Cimento A* [18]. In December 1967, a new preprint version of [11] also appeared [19].

Simultaneously to the statistical bootstrap work of Hagedorn, attempts to relate direct-channel resonances to crossed-channel Regge poles culminated in July 1968 with the Veneziano work [20, 21] introducing the dual models. A few months before, the Harari-Freund picture had been formulated [22, 23] associating through the duality relation Regge poles to direct-channel resonances and the Pomeron to the background. Explicit N-particle dual amplitudes started being built in 1969 and an intermediate particle spectrum described by an infinite set of harmonic oscillators was found (see, for instance, [24–26] and on Nambu's work [27]). The string model developed then quickly and led, in particular, to a "parton view" of dual amplitudes [28, 29] as early as 1970. The authors of [28] state *"that the sum of a large number of "fishnet" Feynman graphs of very high order can be approximated by generalized Veneziano amplitudes"*. Similarly, the abstract of [29] explicitly refers to a "parton picture" of hadrons to claim that *"the limit of the sums of very high order, unrenormalized Feynman diagrams lead to dual N point functions"*. Thus, the underlying composite nature of the internal structure of dual amplitudes (strings) was clearly pointed out three years before the formulation of Quantum Chromodynamics by David Gross, Frank Wilczek and David Politzer [30, 31].

According to Gabriele Veneziano [32], Rolf Hagedorn emphasized in 1994, thirty years after formulating his statistical boostrap theory, that "the dual resonance model or string theory gives a microscopic explanation" for the hadron spectrum he had found using his own approach. After reporting this statement by Hagedorn, Veneziano develops a chapter entitled *A Surprise That Should Not Have Been One* and refers to an article by John Ellis [33] entitled *Hagedorn's Reincarnation in String Theory*. Two recent papers [34, 35] illustrate the current diversity of approaches and applications concerning string theory with Hagedorn thermodynamics

It remains to be seen how a Hagedorn-like thermodynamics can apply to alternative physics involving a new space-time geometry, new ultimate constituents of matter and possibly new Regge-like trajectories. We attempt here to discuss such questions and to suggest new ideas on the subject [36].

2 Hadrons, strings, bootstrap, quarks and gluons in the 1970's

I arrived to CERN, as a fellow, in January 1978. My paper *Structure of the cylinder term in the topological expansion*, with Patrick Aurenche, was then a preprint to appear in *Physical Review* [37]. The goal of the paper was to solve a long-term phenomenological controversy concerning the Pomeron and the f-trajectory and to definitely refute the arguments claiming that the Pomeron trajectory was actually a "promoted f" associated to what was called "f extinction". Such claims had been standing for years, aiming to contradict the Harari-Freund picture as well as the idea that the Pomeron could actually be associated to the "cylinder term" (the box diagram with the "double twist" of the quark lines in the crossed channel) of the dual field theory (see also [38, 39]).

As early as 1970, it had been found [40] that the non-planar box diagram of dual field theory (DFT) yielded a Pomeron-like Regge trajectory with a slope equal to half the initial Regge slope. In spite of its obvious advantages, interpreting this singularity as the Pomeron was rejected by many phenomenologists who stated that this identification would lead to practical inconsistencies and could not reproduce a multiperipheral pattern. In [37], followed by [38, 39]), it was shown that such claims were wrong and that the Pomeron obtained from DFT calculations carries automatically, in its internal structure (the properties of the intermediate states when interpreted in terms of particles and of internal constituents), a consistent multiperipheral description of "soft" hadronic physics.

The practical sense of the concept of bootstrap was thus tacitly debated: should one require to get the laws of Physics from a minimal phenomenological information? Fashionable phenomenology of the 1970's had often been reduced to applying multiperipheral "unitarity corrections" to the exchange of the f trajectory through the production of "clusters" without overlapping in the rapidity space. The DFT Pomeron was thus ignored or rejected, in spite of the fact that dual field theory was the natural consequence of the factorization of dual amplitudes leading to a hadron spectrum consistent with Hagedorn thermodynamics. In [37], taking the two-particle s-channel discontinuity of the one-loop double-twisted graph of DFT, it was shown that the dual field theoretical diagram associated to the Pomeron naturally leads to a multiperipheral pattern involving two kinds of regions in the rapidity space: those with a single jet dominated by a standard Regge exchange (the f, basically) and the regions with a double jet associated to the dual Pomeron exchange.

The analysis was pursued in [38], discussing in particular the role of flavour-loop corrections. In [39], a detailed analysis of the transverse momentum of the intermediate states confirmed the consistency of the dual Pomeron with multiperipheral phenomenology. In the two-jet region, the square of the total transverse momentum of each jet was shown to be proportional to the rapidity length, as expected from an uncorrelated distribution in the rapidity variable. Two-jet models for the Pomeron had been first considered in 1972-1973 by Huan Lee [41] and Gabriele Veneziano [42], but the DFT internal structure of two-jet states remained to be studied explicitly as in [37–39].

Simultaneously to our 1977-79 work, phenomenological studies became less favorable to the Pomeron - f identity. In the 1980's the Pomeron + f pattern was commonly used. In the late 1970's, the phenomenology of Quantum Chromodynamics had also started developing [43, 44].

Furthermore, as early as June 1975, a preon model for quarks and leptons was suggested by Jogesh Pati and Abdus Salam [45, 46]. When the rishon model was published in 1979 [47, 48], I had been considering the same pattern since some time but I had hesitated to publish it. After the papers by Haim Harari and Michael Shupe appeared, I proposed a more sophisticated model involving preonic internal symmetries like SU(2) and a confinement SO(3) [49]. 15 years later [50, 51], I suggested an alternative approach where preons are not constituents of quarks and leptons but of the physical vacuum (the superbradyon approach, where superbradyons are nontachyonic superluminal preons). The standard "elementary" particles are then excitations of the preonic vacuum and can be compared to phonons or solitons in condensed matter [36, 52]. See also [53, 54] and [55, 56].

2.1 The quark-gluon plasma

What about the quark-gluon plasma, that constitutes today a direct experimental evidence for Hagedorn thermodynamics and may even be used to search for superbradyons [27, 36]? In 1975, after Quantum Chromodynamics with asymptotic freedom had been formulated, Nicola Cabibbo and Giorgio Parisi [57] pointed out that the Hagedorn temperature was not necessarily a limiting temperature but could also be associated to a second order phase transition, in particular deconfining quarks.

The new ingredient in the work by Cabibbo and Parisi was to deal with hadrons as extended objects and not just point-like as in the original Hagedorn papers. In January 1985, Rolf Hagedorn wrote [58] on this subject concerning his work of the 1960s:

The missing luck (or missing cleverness) was mainly due to the assumption of pointlike particles. With one exception [POM51] all statistical models made that same mistake at that time. It turned out that for point particles the singularity was such that, when approaching the transition temperature T_0, the energy density would diverge and thus the other phase would be out of reach. Hence T_0 was interpreted as the ultimate temperature.

(en of quote)

The reference [POM51] corresponds to a 1951 article by Isaak Pomeranchuk [59]. Reviews and contributions on the quark-gluon plasma and the experimental studies of this now established phenomenon have been presented at this conference by several authors.

In a preonic picture of vacuum [27, 36, 53, 54, 56], and assuming the standard particles to be vacuum excitations, an equivalent of the updated Hagedorn thermodynamics must in principle be considered at a scale where quarks, gluons, leptons and the photon can no longer be viewed as point-like objects. It may even happen that several such scales occur, especially in the presence of spinorial Regge trajectories and other new sets of particles generated by the dynamics of the preonic vacuum.

3 Spinorial space-time, superbradyonic vacuum and new particles

The spinorial space-time (SST) and the superbradyonic vacuum are discussed in detail in [36], focusing on their possible implications for the origin and actual properties of Quantum Mechanics as already considered in [53, 54] and in [56]. The cosmic SST is centered at the origin of the Universe $\xi = 0$ (vanishing cosmic space and time) where ξ stands for the cosmic space-time position described by a SU(2) spinor in which the four standard real coordinates have been replaced by two complex ones. The space associated to ξ_0 corresponds then to the cosmic hypersphere made of the points whose cosmic spinorial position has the same modulus (the associated cosmic time) as that of ξ_0.

Such a cosmic SST can be complemented, in a suitable approximation and at small enough cosmic distances [36], by a local SST where the SU(2) group acts on the spinorial distance $\xi - \xi_0$. The local world incorporating a preonic (superbradyonic) vacuum with a space-time geometry described by the local SST, where the spin-1/2 particles are actual representations of the local SU(2) space rotation group, can naturally generate spinorial Regge trajectories with an angular momentum spacing of 1/2 instead of 1. The sets of particles lying on these new trajectories can include, for instance, new kinds of matter resulting from specific excitations of the superbradyonic vacuum. The "elementary" particles of the standard model can lie on a spinorial Regge trajectory of this kind with internal symmetries added to the space-time SU(2) and generated as a low-energy limit of preon dynamics.

With such a local SST, a spin-1/2 particle with position at ξ_0 would be a spinorial wave function "centered" at ξ_0 and taking significant values at small enough values of $| \xi - \xi_0 |$ (the modulus of the spinorial distance). The existence of "elementary" spin-3/2 or spin-5/2 particles may thus be naturally generated. The standard Poincaré group is no longer an exact symmetry but a local low-energy limit, and an alternative to supersymmetry (approximate and broken) can emerge [36, 55, 60].

3.1 Search for new particles generated by the preonic vacuum

The search for new particles generated by a local SST geometry together with a preonic vacuum structure is obviously an important and urgent task, already for current CERN experiments. For instance, recent announcements by CMS [61] and ATLAS [62] mention to have observed in both experiments a signal in the diphoton invariant mass spectrum around 750 GeV. Even if the statistical significance remains weak, such a signal is already the subject of an increasing number of theoretical papers traying to explain its origin through all kinds of "classical" and "exotic" phenomena. But actually, such a particle, if it really exists, can be one of the low-energy objects just described generated in a preonic vacuum with a spinorial space-time or another unconventional space-time. If the standard particles actually belong to the same family of preonic vacuum excitations, the couplings for the decay of the possibly detected particles will not necessarily be radically different from the conventional ones.

Actually, as pointed out in [36], a possible direct signature already exists for the superbradyonic vacuum: the long-distance entanglement recently observed in [63, 64], clearly violating Bell inequalities [65, 66]. A strongly superluminal signal and correlation propagation in vacuum can be at the origin of such an entanglement effect observed at a distance of 1.3 kilometers.

Thus, assuming preons to be the constituents of the physical vacuum (the superbradyon hypothesis [50, 51]) instead of "quark like" constituents of the standard particles as initially postulated by authors of the 1970's articles, opens the way to a large set of phenomenological potentialities that must be seriously explored [27]). If the standard "elementary" particles are actually low-energy excitations of a superbradyonic vacuum with a spinorial space-time geometry, and if other excitations of this vacuum exist (the recently observed LHC dipole signal can be an example), new superluminal particles (not tachyons) with a critical speed not radically different from c can be not too weakly coupled to standard particles, and a new Hagedorn-like thermodynamics can hold for such a global dynamical structure.

3.2 Some open questions

At this stage, a series of crucial questions arises. In particular: : i) can superbradyons exist as free particles? ; ii) can they exist as confined in a "plasma" resulting from collisions between standard particles? ; iii) what are the space, time, momentum, energy... scales at which standard particles start existing in the superbradyonic vacuum? ; iv) does the Planck scale still make any sense? ; v) what is (are) the critical speed(s) of superbradyons, inside vacuum and possibly as free particles? ; vi) what are the thermodynamics and the internal temperature of the physical vacuum? ; vii) what can be the physical laws governing superbradyon interactions? ... Obvioulsy, a long-term work is required in experimental particle physics and cosmological observations, including new accelerators, satellite programs and Earth-based detection of ultra-high energy cosmic rays (UHECR) [53, 56].

Also, as discussed in [36], the possibility of a contradiction at very small space-time scales between the local SST (or a similar unconventional space-time) and the extrapolation of the macroscopic cosmic one must be taken into account, as well as its possible consequences for particle propagation and the generation of Quantum Mechanics (see also [54, 67] and [68, 69]. In such a scenario, the relevant space-time scale corresponds to the spinorial size of the particle internal structure, and slightly above this scale. Again, the conventional Planck scale [70] can be totally bypassed by such a fundamental process and in any case a long-term experimental and observational effort will be required to find signatures of the relevant space, time, momentum and energy scales for the generation of standard particles. The question of a Hagedorn-like themodynamics sensitive to these scales must also be raised like, more generally, that of the internal vacuum and particle structure.

Another important question just tacitly raised is: do all the particles generated as excitations of the surperbradyonic vacuum have the same critical speed? This can be natural for all particles lying

on the same multiplets and spinorial Regge trajectories as the conventional particles, but less obvious for other vacuum excitations that can possibly have critical speeds larger than c. The spinorial size of such particles would in principle be different from that of the standard particles. Similarly, the vacuum structure in terms of superbradyons ("plasma"?, "condensed matter"?) requires a serious reflexion.

4 Cosmology with SST and a superbradyonic vacuum

Applications to Astrophysics of the statistical thermodynamics of hadrons were already suggested by Rolf Hagedorn as early as April 1969, leading to a September 1969 preprint published in 1970 [71]. Hagedorn thermodynamics is now a permanent ingredient of string theory and Cosmology.

An alternative to strings and standard Cosmology is provided by preon models and pre-Big Bang [53, 56]. In this kind of patterns, Hagedorn-like temperatures are also expected to be present.

In all cases, assuming superluminal free particles can exist, simple phase space considerations can explain that they have gradually disappeared at early stages of the history of our Universe [53, 56]. For a given energy, the momentum phase space is smaller when the critical speed is larger. The production of such particles becomes therefore more difficult. Simultaneously, these particles decay into other particles with a smaller critical speed. This kind of considerations would apply to superbradyons if they can be materialized as free particles, as well as to vacuum excitations with a critical speed larger than c. Thus, the actual cosmological evolution is finally dominated by the particles with the lowest critical speed (the standard particles and possible similar new ones). Some superluminal particles can remain, forming a sea with speeds close to c, and be part of the dark matter [55, 72].

Pre-Big Bang with a superbradyonic vacuum eliminates any need for an inflationary period and, simultaneously, replaces the Planck scale by new scales associated to the dynamics introduced [53, 56]. The phases of the history of the Universe generated by this dynamics can naturally involve a Hagedorn-like thermodynamics. Similarly, the SST Universe can be hyperspherical but appear to us as flat because of its size beyond direct observation [53, 56].

Actually, just as long-distance quantum entanglement provides a potential evidence for the superbradyonic vacuum, a specific prediction of the cosmic SST geometry seems to have been confirmed by observation. A 2013 Planck result [73] found the existence of a preferred space direction with a clear difference in power spectrum between the two hemispheres. Such an announcement seems to have survived to 2015 analyses and corrections [74, 75]. This 2013 Planck result corresponds to a natural prediction of the SST already found in [76] and stressed in [55, 56]. The local privileged space direction (PSD) for each comoving observer is a direct consequence of the cosmic spinorial coordinates and corresponds to multiplying the cosmic spinor by a complex phase (see also [53, 56]).

Thus, the SST + superbradyonic vacuum scenario may have already been confirmed by experimental and observational data. Further work in this direction is obviously required.

Again, important questions remain open and require further study [27]. What can be the dynamics behind the cosmic spinorial space-time, in particular around $\xi = 0$ when the superbradyonic vacuum starts developping ? And if standard particles are soliton-like solutions of the vacuum equations, what is the situation concerning plane waves? How does the vacuum interact with conventional matter, including the quark-gluon plasma? Can there be exchanges of energy and momentum? Can the quark-gluon plasma emit superluminal particles? What is the difference between the vacuum configuration in regions of space with almost no standard matter and in the presence of important matter densities?

The study of such questions will in particular involve thermodynamical issues and considerations, new theoretical efforts, new experiments and observations beyond the standard Casimir effect [77], further work on quantum field theory and on the vacuum structure [53, 56]... Preonic approaches appear particularly well suited to settle problems related to the quantum-field-theoretical structure of vacuum and can yield natural, powerful solutions (see also [36] and references therein).

5 Conclusion and comments

Resulting from an original, long-term work made in the 1960's, the statistical thermodynamics of strong interactions has become a basic component of Particle Physics and Cosmology.

After the initial Hagedorn work and the 1975 paper by Cabibbo and Parisi [57], Rolf Hagedorn, Istvan Montvay and Johann Rafelski (December 1978) [78] and subsequently Johann Rafelski and Rolf Hagedorn (April 1979) [79] presented an updated version of the statistical boostrap model studying the thermodynamics of hot nuclear matter. Later, Johann Rafelski suggested to study the properties of nuclear matter through the annihilation of antiprotons with momenta of 0.5-1.5 GeV/c at LEAR (Low Energy Antiproton Ring) colliding with heavy nuclei [80]. A subsequent paper by Johann Rafelski, Hans-Thomas Elze and Rolf Hagedorn [81] focused on hot hadronic matter and hot quark-gluon plasma. Thus, Hagedorn was already involved in the search for the quark-gluon plasma at CERN.

If the theoretical transition from hadrons to quarks was a fundamental one in the 1960s and 1970s, the same can happen at present with a transition from standard particles to preons if the basic idea is correct. But contrary to the Quantum Chromodynamics of the 1970s, there is by now no precise theory of preon dynamics. The superbradyon hypothesis helps to clarify the situation by setting preons to be (naturally superluminal) constituents of the physical vacuum and not "quark-like" constituents of the standard particles as initially assumed in the 1970s. But exploring the internal vacuum dynamics will certainly be much more difficult than building a theory of quarks with a suitable phenomenology.

In [36], a possible fundamental origin of Quantum Mechanics has been dealt with based on the spinorial space-time with a dynamical preonic (superbradyonic) vacuum. Experimental tests of Quantum Mechanics, including at the highest cosmic-ray energies and searching for signatures of a deformation, can help to understand vacuum and (possibly) superbradyon dynamics.

As previously emphasized, recent results on long-distance quantum entanglement and the privileged space direction recently observed by Planck are a strong potential evidence for a superbradyonic vacuum with a SST geometry. New theoretical studies, as well as new generations of experiments and observations, must pay particular attention to these two features of data. Actually, a global long-term experimental an observational effort will be required to really understand the properties of the preonic vacuum and superbradyons, assuming that these hypotheses correspond to the physical reality.

Spinorial Regge trajectories and other kinds of families of excitations of the superbradyonic vacuum with SST, including the standard particles and members of associated multiplets and trajectories, deserve an active exploration at accelerators without forgetting the possible production of superluminal objects. Such an alternative to standard strings does not appear to be less justified.

References

[1] R. Hagedorn: *Statistical thermodynamics of strong interactions at high-energies*, CERN preprint CM-P0057114, http://cds.cern.ch/record/346206/files/CM-P0057114.pdf

[2] R. Hagedorn: *Statistical thermodynamics of strong interactions at high-energies*, *Nuovo Cim. Suppl.* **3**, 147 (1965). Also published in *Quark-Gluon Plasma: Theoretical Foundations*, edited by J.I. Kapusta, B. Müller and J. Rafelski, North-Holland (Elsevier) 2003.

[3] R. Hagedorn, *Thermodynamics of Distinguishable Particles: A Key to High-Energy Strong Interactions?*, CERN preprint CM-P0056976, 12 October 1964, http://cds.cern.ch/record/929730/files/CM-P0056976.pdf

[4] The main work of Rolf Hagedorn is explained and reproduced in the book *Melting Hadrons, Boiling Quarks* (Springer), edited by Johann Rafelski. Freely available at the address http://www.springer.com/la/book/9783319175447

[5] V. Petrov, *Half a Century with Quarks*, arXiv:1412.8681.

[6] G. Zweig, *Concrete Quarks - The Beginning of the End*, talk given at the 2nd International Conference on New Frontiers in Physics, Kolymbari, Crete, Greece, August 28 - September 5, 2013, *EPJ Web of Conferences* **71**, 00146 (2014).

[7] M. Gell-Mann,*A schematic model of baryons and mesons*, *Phys. Lett.* **8**, 214 (1964). Available at the address http://hep.caltech.edu/gm/images/quarks.pdf (Caltech).

[8] G. Zweig, *An SU_3 model for strong interaction symmetry and its breaking*, CERN TH preprint 17 January 1964, http://cds.cern.ch/record/352337/files/CERN-TH-401.pdf

[9] G. Zweig, *An SU_3 model for strong interaction symmetry and its breaking. II*, CERN TH preprint 21 February 1964, http://cds.cern.ch/record/570209/files/CERN-TH-412.pdf

[10] A. Petermann, *Propriétés de l'étrangeté et une formule de masse pour les mésons vectoriels*, *Nucl. Phys.* **63**, 349 (1965), received 30 December 1963.

[11] R. Hagedorn and J. Ranft, *Statistical thermodynamics of strong interactions at high-energies - II (Momentum spectra of particles produced in high energy pp collisions)*, CERN preprint CM-P0057348, 30 September 1966, http://cds.cern.ch/record/933372/files/ CM-P0057348.pdf

[12] R. Hagedorn and J. Ranft, *Statistical thermodynamics of strong interactions at high-energies - III. Heavy pair (quark) production rates*, CERN preprint CM-P0057552, 3 April 1967, http://cds.cern.ch/record/936485/files/CM-P0057552.pdf

[13] R. Hagedorn and J. Ranft, *Statistical thermodynamics of strong interactions at high-energies. 2. Momentum spectra of particles produced in high energy pp collisions*, *Nuovo Cim. Suppl.* **6**, 169 (1968).

[14] R. Hagedorn and J. Ranft, *Statistical thermodynamics of strong interactions at high energies. 3. Heavy-pair (quark) production rates*, *Nuovo Cim. Suppl.* **6**, 311 (1968).

[15] R. Hagedorn, *On the hadronic mass spectrum*, CERN preprint CM-P0057745, 12 september 1967, http://inspirehep.net/record/1384659/files/CM-P00057745.pdf

[16] R. Hagedorn, *On the hadronic mass spectrum*, *Nuovo Cimento* **A52**, 1336 (1967). Available in open access in the book *Melting Hadrons, Boiling Quarks*.

[17] R. Hagedorn, *Hadronic matter near the boiling point*, CERN preprint CM-P0057767, 27 november 1967, http://cds.cern.ch/record/347805/files/CM-P0057767.pdf

[18] R. Hagedorn, *Hadronic matter near the boiling point*, *Nouvo Cimento* **A56**, 1027 (1968).

[19] R. Hagedorn and J. Ranft, *Statistical thermodynamics of strong interactions at high-energies - II. Momentum spectra of particles produced in high energy pp collisions*, CERN preprint CM-P0057765, December 1967, http://cds.cern.ch/record/938671/files/CM-P0057765.pdf

[20] G. Veneziano, *Construction of a crossing symmetric, Regge behaved amplitude for linearly rising trajectories*, CERN preprint CM-P0057839, 19 July 1968,)http://cds.cern.ch/record/390478/files/CM-P0057839.pdf

[21] G. Veneziano, *Construction of a crossing symmetric, Regge behaved amplitude for linearly rising trajectories*, *Nuovo Cimento A57*, 190 (September 1968).

[22] H. Harari, *Pomeranchuk Trajectory and its relation to low-energy scattering amplitudes*, *Phys. Rev. Lett.* **20**, 1395 (June 1968). Received 26 February 1968. Available at the address http://www.weizmann.ac.il/particle/harari//files/PhysRevLett.20.1395.pdf (Weizmann Institute)

[23] P. Freund, *Finite-Energy Sum Rules and Bootstraps*, *Phys. Rev. Lett.* **20**, 235 (January 1968), received 8 December 1967.

[24] S. Fubini and G. Veneziano, *Level Structure of Dual Resonance Models*, *Nuovo Cimento 64A*, 811 (1969).

[25] K. Bardakci and S. Mandelstam, *Analytic Solution of the Linear-Trajectory Bootstrap*, *Phys. Rev. 184*, 1640 (1969).

[26] M. Virasoro, *Subsidiary Conditions and Ghosts in Dual Resonance Models*, *Phys.Rev.* **D1**, 2933 (1970).

[27] See also our talk *Big Bang, inflation, standard Physics... and the potentialities of new Physics and alternative cosmologies*, https://indico.cern.ch/event/344173/session/4/contribution/277 (this Conference).

[28] B. Sakita and M. A. Virasoro, *Dynamical Model of Dual Amplitudes Phys. Rev.Lett. 24*, 1146 (1970).

[29] H.B. Nielsen and P. Olesen, *A Parton View on Dual Amplitudes*, *Phys. Lett.* **32B**,203 (1970). CERN preprint CM-P00058602.pdf (May 1970), http://cds.cern.ch/record/350954/files/CM-P00058602.pdf

[30] D. Gross and F. Wilczek, *Ultraviolet Behavior of Non-Abelian Gauge Theories*, *Phys. Rev. Lett.* **30**, 1343 (1973), http://www.aps.org/about/pressreleases/upload/Ultraviolet_Behavior_of_Non_Abelian_Gauge_Theory.pdf

[31] H.Politzer, *Reliable Perturbative Results for Strong Interactions? Phys. Rev. Lett.* **30**, 1346 (1973), http://wwwphy.princeton.edu/~kirkmcd/examples/EP/politzer_prl_30_1346_73.pdf

[32] G. Veneziano, *The Hagedorn Spectrum and the Dual Resonance Model: An Old Love Affair*, event *Hagedorn's Legacy*, CERN, 13 November 2015, https://indico.cern.ch/event/446994/. Published in *Melting Hadrons, Boiling Quarks*.

[33] J. Ellis, *Hagedorn's Reincarnation in String Theory*, 27 Jun 1994 Meeting, Divonne-les-Bains, France. Published in *Hot Hadronic Matter*, edited by Jean Letessier, Hans H. Gutbrod and Johann Rafelski, NATO ASI Series, Volume **346** (Springer, 1995).

[34] C. Thorn, *String Bits at Finite Temperature and the Hagedorn Phase*, arXiv:1507.03036, and references therein.

[35] T. Mertens (Thesis), *Hagedorn String Thermodynamics in Curved Spacetimes and near Black Hole Horizons*, arXiv:1506.07798, and references therein.

[36] Complementary material is provided in our contribution to this conference *Spinorial space-time and the origin of Quantum Mechanics*, https://indico.cern.ch/event/344173/session/22/contribution /405

[37] P. Aurenche and L. Gonzalez-Mestres, *Phys. Rev.* **D 18**, 2995 (1978). Received 29 August 1977, revised manuscript received 17 January 1978. Preprint LPTHE 77/33.

[38] P. Aurenche and L. Gonzalez-Mestres, *Glueball singularity, flavour loops and the Harari-Freund picture*, *Zeitschrift für Physik* **C1**, 307 (1979) https://cds.cern.ch/record/133138/files/CM-P00061765.pdf

[39] L. Gonzalez-Mestres and P. Aurenche, *Glueball-Pomeron identity and the transverse structure of two-jet events*, *Zeitschrift für Physik* **C2**, 339 (1979), http://cds.cern.ch/record/133286/files/197904147.pdf

[40] G. Frye and L. Susskind, *Non-planar dual symmetric loop graphs and the pomeron*, *Phys. Lett.* **B31**, 589 (1970).

[41] Huan Lee, *How to Generate the Pomeranchukon from the Background in a Dual Multiperipheral Model*, *Phys. Rev. Lett.* **30**, 719 (1973).

[42] G. Veneziano, *Origin and intercept of the Pomeranchuk singularity*, *Physics Letters* **B43**, 413 (1973).

[43] K. Shizuya and S.-H.H. Tye, *QCD Phenomenology of Gluon Jets*, *Phys. Rev.* **D20**, 1101 (1979) and Erratum, *Phys. Rev.* **D21**, 313 (1980). Fermilab preprint FERMILAB-Pub-79/16-THY,

http://lss.fnal.gov/archive/1979/pub/Pub-79-016-T.pdf

[44] G.P. Lepage and S. Brodsky, *Exclusive Processes in Perturbative Quantum Chromodynamics*, *Phys. Rev.* **D22**, 2157 (1980), and references therein. Preprint SLAC-PUB-2478 (March 1980), http://inspirehep.net/record/153236/files/slac-pub-2478.pdf

[45] J. Pati and A. Salam, *Quarks, leptons and pre-quarks*, ICTP (Trieste) report IC1975106, available by a search at the ICTP archive : http://cat.ictp.it/F/?func=find-b&local_base=WEBALL

[46] See also J. Pati, A. Salam and J. Strathdee, *Are Quarks Composite?*, *Phys. Lett.* **B59**, 265 (1975). Preprint available by a search at the ICTP archive.

[47] H. Harari, *A schematic model of quarks and leptons*, *Phys. Lett.* **B86**, 83 (1979). Available at the address http://www.weizmann.ac.il/particle/harari//files/schematic_model_of_quarks_and_leptons.pdf (Weizmann Institute).

[48] M. Shupe, *A composite model of leptons and quarks*, *Phys. Lett.* **B86**, 87 (1979).

[49] L. Gonzalez-Mestres, *Quarklike composite model of quarks and leptons*, *Phys. Rev.* **D23**, 2055 (1981). Received 28 March 1980.

[50] L. Gonzalez-Mestres, *Properties of a possible class of particles able to travel faster than light*, Proceedings of the January 1995 Moriond Workshop, Ed. Frontières, arXiv:astro-ph/9505117.

[51] L. Gonzalez-Mestres, *Cosmological Implications of a Possible Class of Particles Able to Travel Faster than Light*, Proceedings of the TAUP 1995 Conference, *Nucl. Phys. Proc. Suppl.* **48** (1996), 131, arXiv:astro-ph/9601090.

[52] L. Gonzalez-Mestres, *Vacuum Structure, Lorentz Symmetry and Superluminal Particles*, arXiv:physics/9704017

[53] L. Gonzalez-Mestres, *BICEP2, Planck, spinorial space-time, pre-Big Bang*, invited talk at the 3rd International Conference on New Frontiers in Physics (ICNFP 2014), Kolymbari, Crete, Greece, August 23 - 30, 2014, *EPJ Web of Conferences* **95**, 03014 (2015), and references therein.

[54] L. Gonzalez-Mestres, *Tests and prospects of new physics at very high energy*, contribution the 3rd International Conference on New Frontiers in Physics, Kolymbari, Crete, Greece, August 23 - 30, 2014, *EPJ Web of Conferences* **95**, 05007 (2015), and references therein.

[55] L. Gonzalez-Mestres, *Cosmic rays and tests of fundamental principles*, CRIS 2010 Proceedings, *Nucl. Phys. B, Proc. Suppl.* **212-213** (2011), 26, and references therein. The *arXiv.org* version arXiv:1011.4889 includes a relevant Post Scriptum.

[56] See also our contributions to the ICNFP 2012 and ICNFP 2013 Conferences.

[57] N. Cabibbo and G. Parisi, *Exponential hadronic spectrum and quark liberation*, *Phys. Lett.* **B59**, 67 (1975).

[58] R. Hagedorn, *Miscellaneous elementary remarks about the phase transition from a hadron gas to a gluon plasma*, CERN preprint TH.4100/85, January 1985, http://cds.cern.ch/record/158166/files/198504017.pdf

[59] I. Pomeranchuk, *On the theory of production of many particles in a single act*, *Doklady Akademii Nauk sssr* **78**, 889 (1951).

[60] L. Gonzalez-Mestres *Pre-Big Bang, fundamental Physics and noncyclic cosmologies*, presented at the International Conference on New Frontiers in Physics, ICFP 2012, Kolymbari, Crete, June 10-16 2012, *EPJ Web of Conferences* **70**, 00035 (2014), and references therein. Preprint version at mp_arc 13-18.

[61] The CMS Collaboration, *CMS Physics Analysis Summary*, 18 December 2015, https://cds.cern.ch/record/2114808/files/EXO-15-004-pas.pdf

[62] The ATLAS Collaboration, ATLAS-CONF-2015-081, 15 December 2015, http://cds.cern.ch/record/2114853/files/ATLAS-CONF-2015-081.pdf

[63] B. Hensen et al., *Experimental loophole-free violation of a Bell inequality using entangled electron spins separated by 1.3 km*, *Nature* **526**, 682 (2015), arXiv:1508.05949.

[64] M. Giustina et al., *A significant-loophole-free test of Bell's theorem with entangled photons*, arXiv:1511.03190.

[65] J.S. Bell, *Speakable and Unspeakable in Quantum Mechanics: Collected Papers on Quantum Philosophy*, Cambridge University Press, 2004.

[66] J. Clauser, M. Horne, A. Shimony and R. Holt, *Proposed experiment to test local hidden-variable theories*, *Physical Revew Letters* **23**, 880 (1969). Available at http://users.unimi.it/aqm/wp-content/uploads/CHSH.pdf

[67] L. Gonzalez-Mestres, *Quantum Mechanics and the Spinorial Space-Time*, mp_arc 15-86.

[68] L. Gonzalez-Mestres, *Quantum Mechanics, preonic vacuum and space-time contradiction*, mp_arc 15-90.

[69] L. Gonzalez-Mestres, *Quantum Mechanics, space-time, preons and entanglement*, mp_arc 15-92

[70] The standard Planck scale is actually very old: M. Planck, *Über irreversible Strahlungsvorgänge,*, *S.B. Preuss. Akad. Wiss.* (1889), 440 and *Annalen der Physik* **1**, 69 (1900). Available at the address http://vincent.rossetto.free.fr/physique/ref/planck1900.pdf

[71] R. Hagedorn, *Thermodynamics of strong interactions at high-energy and its consequences for astrophysics*, *Astron. Astrophys.* **5**, 184 (1970), CERN preprint CM-P00058250, http://cds.cern.ch/record/350701/files/CM-P00058250.pdf

[72] L. Gonzalez-Mestres, *Lorentz symmetry violation, dark matter and dark energy*, contribution to the Invisible Universe International Conference, Paris June 29 - July 3, 2009. The *arXiv.org* version arXiv:0912.0725 contains a Post Scriptum and an additional note.

[73] The Planck Collaboration, *Planck 2013 results. XXIII. Isotropy and statistics of the CMB*, *Astron.Astrophys. 571*, A23 (2014), arXiv:1303.5083.

[74] The Planck Collaboration, *Planck 2015 results. XVI. Isotropy and statistics of the CMB*, arXiv:1506.07135.

[75] See, for instance, E. Martinez-Gonzalez on the behalf of the Planck Collaboration, transparencies presented at the Fundamental Cosmology meeting, Santander June 17th-19th, 2015.

[76] L. Gonzalez-Mestres, *Space, Time and Superluminal Particles*, arXiv:physics/9702026.

[77] For a recent review on the Casimir effet, see for instance G. L. Klimchitskaya and V. M. Mostepanenko, *Casimir and van der Waals forces: Advances and problems*, arXiv:1507.02393.

[78] R. Hagedorn, I. Montvay and J. Rafelski, *Thermodynamics of hot nuclear matter from the statistical bootstrap model*, Workshop on Hadronic Matter at Extreme Energy Density "Ettore Majorana", Erice, 13 - 21 October 1978, p.49. Available at the address http://www.physics.arizona.edu/ rafelski/Books/78EriceHagRaf.pdf (University of Arizona).

[79] J. Rafelski and R. Hagedorn, *Thermodynamics of hot nuclear matter in the statistical bootstrap model*, 17th International Winter Meeting on Nuclear Physics, Bormio, Italy, 22 - 27 Jan 1979, p.531. CERN preprint CM-P0005555 (April 1979), http://cds.cern.ch/record/134674/files/CM-P00055555.pdf

[80] J. Rafelski, *$\bar{p}$ annihilation on heavy nuclei*, *Phys. Lett.* **B91**, 281 (1980). CERN preprint TH.260, available at http://ccdb5fs.kek.jp/cgi-bin/img/allpdf?197911276

[81] J. Rafelski, H.-Th.Elze and R. Hagedorn, *Hot hadronic and quark matter in $\bar{p}$ annihilation on nuclei*, 5th European Symposium on Nucleon-antinucleon Interactions, Bressanone, Italy, 23 - 28 Jun 1980, p. 357, CERN preprint CM-P00061794, https://cds.cern.ch/record/982871/files/CM-P00061794.pdf